

EXPERIMENTAL INVESTIGATION OF THERMAL EFFICIENCY OF BOILING POT WITH MODIFIED SURFACE GEOMETRY

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ABSTRACT

The research investigates the feasibility of a boiling pot with modified bottom surface as an efficient way compared to the boiling pot with a flat bottom. The effects of multiple vertical tubes along with modified bottom pot surface on heat transfer are also investigated experimentally. There are five types of pots used during the experiments. The first one is of flat bottom; the others are of different modified bottom with vertical tubes. Water boiling test (WBT) is used to calculate the thermal efficiency. The results obtained from the modified cooking pot are compared with the unmodified flat bottom cooking pot. The pots with modified bottom with vertical tubes give 25-29% higher efficiency than that of the flat bottom pot. Also in case of modified pots the boiling point is reached at a lesser time compared to that of flat bottom. The results of this study are of technological importance for the efficient design of domestic cooking pots to enhance performance.

KEYWORDS: Boiling Pot; Flue Tube, Heat Transfer Enhancement, Modified Bottom & Thermal Efficiency

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INTRODUCTION

Among various researches to meet the rising demand of global energy in a sustainable manner using gaseous fuels, improving heat transfer for boiling water has been at the forefront of engineering research. During boiling of water in a pot, there is loss of energy due to three main mechanisms: loss of heat from the flames by convection and radiation; energy carried by the water vapour during evaporation. In pots (open vessels), the loss due to evaporation cannot be prevented, but the loss due to convection and radiation can be reduced by modifying the pot shape. In passive enhancement methods, no external power required to enhance the heat transfer. Examples of some passive enhancing methods are: (a) extended surfaces (b) rough surfaces (c) treated surfaces (d) coiled tubes (e) swirl flow devices and many others. The high heat transfer rates associated with boiling are essential to household as well as industrial applications; but boiling is also associated with violent instabilities at high heat flux and poor thermodynamic efficiencies at low heat flux. Researchers have experimented since the 1930's to construct surfaces which improve heat transfer during boiling. The development of micro and nano technologies has made feasible, the high-resolution control of surface texture and chemistry over length scales ranging from molecular levels to centimetres. However, practically least information is available in the literature published on energy conservation in cooking. It may be noted that cooking is also a physio-chemical process, like in the Chemical Process Industry (CPI) and hence, there is a possibility of applying energy conservation methods in cooking practices. A number of researches have been done in improving stove design. Sharma et al. [1] studied the thermal

performance of the wood cook stove with different power inputs. Bhattacharya et al. [2] considered the effects of various parameters on thermal performance and emission of the cook stoves. It was found that as the moisture content in fuel increases stove efficiency decreases, also there is increase in CO emission and decrease in NO_x emission. The role of surface structures in boiling heat transfer enhancement has been attributed to various factors, like capillary wicking[3,4,5,6]increased contact line pinning [7] and increased nucleation site densities[3, 8]. S. Das and S. Bhumik [9] used untreated andretreated surfaces for heating to find boiling heat transfer coefficient. The surfaces were treated with TiO₂ nanoscale coating of thicknesses 100, 200 and 300 nm. He observed that thin film surface is superior to the treated and untreated surfaces. R. I Elghanam et al.[10] Experimented through nucleate pool boiling test to investigates the heat transfer performance of different solutions by adding definite amounts of surfactants to boiling distilled water. The investigations showed that the addition of surfactants like SDS, SLES and Triton X-100 improve the heat transfer coefficient by 132% for Triton X-100, 194% for SLFS and 240% for SDS. Also there is a correlation between the active nucleation site density, wall heat flux and wall superheat. Das et al., [13] adopted basic tunnel structure over flat surface for heat transfer enhancement. Experimental results

Nomenclatures

T_1 Initial temperature in °C

T_2 Boiling point temperature in °C

m_w Weight of water at the beginning of the test in kg

C_p Specific heat water at constant pressure (4.186 kJ/kg°C)

CV_f Lower heating value of consumed gas (49 MJ/kg)

m_f Amount of gas consumed (kg)

Greek symbols

η Thermal efficiency

Abbreviations

LPG Liquefied petroleum gas

Pot-1 Pot having flat bottom

Pot-2 Pot having concave bottom

Pot-3 Pot bottom having concave shape with a central tube

Pot-4 Pot bottom having outer concave and centrally convex with three tubes

Pot-5 Pot bottom having outer concave and central inverted frustum with three tubes

Showed that at an inclination angle of 60° with horizontal the heat transfer is better compared to that in vertical tunnels.

They also found that base with circular pocket geometry provides the most conducive condition for the boiling heat transfer. Bonjour et al. [14] studied the flow patterns during boiling in a narrow space between two vertical surfaces and found that heat flux plays the major role in enhancing the boiling heat transfer. Rahman et al.[15] experimented on structured surfaces and found that boiling heat transfer is increased greatly using structured surfaces, but the reliability of these approaches for practical applications is in question due to a number of reasons. In most of the structured surfaces there is a chance of mechanical failure due to breaking of the micro or nano-structures. Also the dirt deposition leads to clog the surface over time. During boiling, some contaminants present in the fluid are inevitably drawn into the structured area. This leads to clogging of the small micro/nano-scale voids, and hence a loss of heat transfer enhancement.

There are many research works done on the enhancement of thermal performance during pool boiling using electrical heater and the performance of various cooking stoves. However, the present work is focused on the boiling pots of modified bottom surfaces with vertical flue gas passages for heat transfer. The influence of such surfaces is of high

practical interest during boiling.

GEOMETRIC CONFIGURATIONS

The basic form of all the vessels is cylindrical and the heat transfer occurs mainly through the bottom surface and flue tubes. The schematic diagram of different pot bottoms are shown in Figure. 1.

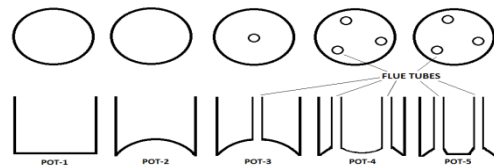


Figure 1: Schematic Diagram of Different Pots



Figure 2(a): Side View of Pot-1



Figure 2(b): Bottom View of Pot-1



Figure 2(c): Top View of Pot-1



Figure 3(a): Side View of Pot-2



Figure 3(b): Bottom View of Pot-2



Figure 3(c): Top View of Pot-2



Figure 4(a): Side View of Pot-3



Figure 4(b): Bottom View of Pot-3



Figure 4(c): Top View of Pot-3



Figure 5(a): Side View of Pot-4



Figure 5(b): Bottom View of Pot-4



Figure 5(c): Top View of Pot-4

**Figure 6(a): Side View of Pot-5****Figure 6(b): Bottom View of Pot-5****Figure 6(c): Top View of Pot-5**

The standard flat bottom vessel and the modified vessels (Figure. 2 to Figure. 6) are fabricated from the galvanized iron sheet of 0.125 cm thick each with diameter of 15 cm and height of 15 cm. To reduce the convective heat loss, the modified cooking pots are brazed with 10 mm flue gas obstructer at the bottom side of the skirt to restrict the flue gas flow along the side of the pot. Also vertical tubes of 1.9 cm internal diameter with same height of container are fabricated at the bottom of the pot for passage of flue gas.

The vessels of the following geometry have been considered in these experiments:

- In pot-1, the bottom of the vessel is a circular lamina, and no flue tubes or flue gas obstructer are provided. In this case, the heat transfer occurs through the bottom and the skirt.
- In pot-2, the bottom surface is part of a hemisphere having curvature radius of 10 cm. The contact surface of the pot with the hot gases is more than that of pot-1.
- In pot -3, the bottom surface is part of a hemisphere with a flue tube at the base centre. The contact surface area is more than that of pot-2 due to presence of the flue tube.
- In pot-4, the bottom surface is further modified by making it partly concave and partly convex. The bottom of the pot is of convex shape with curvature radius of 10 cm surrounded by concave surface with curvature radius of 10 cm. Three cylindrical tubes are placed at the junction of the concave and convex surfaces equidistant from the centre. The bottom surface area is almost same as that of pot-3, but the contact surface is increased due to the presence of the three flue tubes.
- In pot-5, bottom surface is also modified by making it partly concave and partly inverted frustum of a cone. Three cylindrical tubes are also placed equidistant from the centre at the junction of the concave and inverted frustum surfaces for passage of flue gas.

EXPERIMENTAL SETUP AND METHOD

Test Set Up

Figure 7 shows the schematic diagram of the experimental apparatus. The test loop consists of the test pots, LPG cylinder with attached stove and temperature indicator. To supply constant heat flux for a set of observations for all pots, the experiment is conducted with LPG fuel at a fixed fuel flow rate.

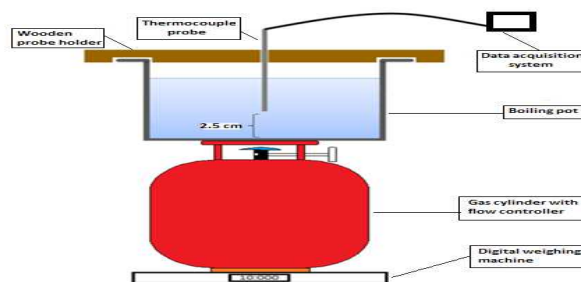


Figure 7: Schematic Diagram of Experimental Setup

A digital weighing machine having least count 0.002 kg is placed at a levelled surface to obtain proper weight. Then a filled LPG cylinder with attached stove is kept on the weighing machine. Pot containing required quantity of distilled water is placed over the stove burner. Wooden probe holder is fixed over the pot to hold the type-T copper-constantan thermocouple. The thermocouple is connected with a data acquisition system to record the transient temperature. The thermocouple tip is positioned centrally in water 2.5 cm above the bottom of the pot. The variation of thermocouple position in vertical direction hardly affects the temperature (Ref. Dr. Alan Berick, Approvecho Research Centre) as shown in Figure 8.

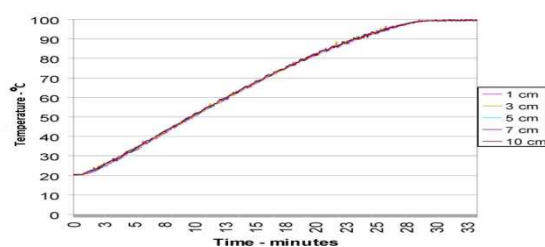


Figure 8: Uniformity in Temperature Distribution in Vertical Direction

Methodology

Each empty boiling pot is cleaned, dried and its weight is measured. The pot is then filled with 1.5 kg of distilled water and the temperature of water is noted. Then the LPG cylinder attached with stove is placed over the digital weighing machine and its weight is measured. The stove burner is cleaned properly before conducting any experiment. Gas stove is ignited and the gas flow rate is maintained constant by the flow controller. Boiling pot containing water is placed properly on the cook top so that water is not spilled away during boiling and then a thermocouple is inserted into the pot. The weight of gas cylinder attached with stove along with water filled pot is recorded. Readings of weighing machine as well as thermocouple are noted at an interval of one minute during the experiment. The experiment is conducted till the boiling point is reached. Then the boiling pot is removed and the weight of the cylinder attached with stove is noted immediately without disturbing the flow controller. The difference in weight of LPG cylinder attached with stove before and after the experiment gives the weight of gas consumption. Also the weight of water evaporated is obtained by the difference between the weight of water before and after the experiment. A set of similar experiments are also conducted for other pots with same gas flow rate. Three sets of such experiments are conducted for different gas flow rates.

THERMAL EFFICIENCY

Thermal efficiency is a measure of the fraction of heat produced by the fuel that transfers to the water in the pot. The remaining energy is lost to the environment. So a higher thermal efficiency greater the quantity of heat transferred

to water in the pot. While heating water from initial temperature $T_1^\circ\text{C}$ to the boiling point temperature $T_2^\circ\text{C}$ water in the vessel gains sensible heat by the combustion of LPG. Subsequent supply of heat causes water to boil by receiving latent heat of vaporization and evaporate. Input energy is calculated by fuel consumption during the process.

Efficiency is calculated by using the following formula:

$$\eta = \frac{m_w C_p (T_2 - T_1)}{CV_f m_f} \times 100\%$$

RESULTS

The experiments have been conducted with five pots of different modifications. For each pot, the experiments have been conducted at four different fuel flow rates. Each experiment is conducted with 1.5 kg of distilled water at the beginning. The efficiency of different pots for various flow rates is discussed.

DISCUSSIONS

Variation of Water Temperature with Time

Figures 9 to 12 show the variation of temperature of water in different pots with time for various fuel flow rates.

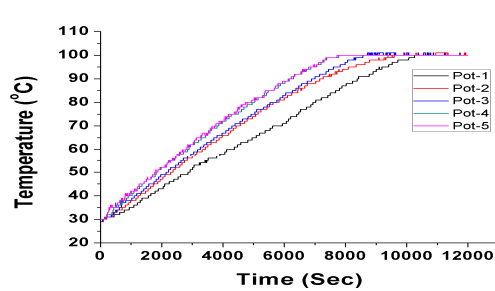


Figure 9: Variation in Temperature with Time at Low Flow Rate

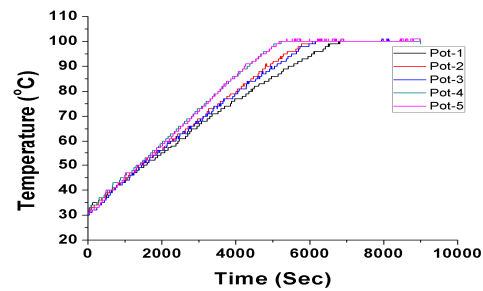


Figure 10: Variation in Temperature with Time at Medium Flow Rate

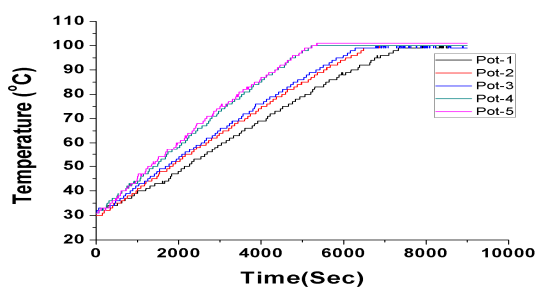


Figure 11: Variation in Temperature with Time at High Flow Rate

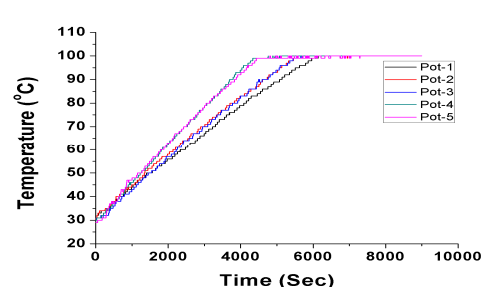


Figure 12: Variation in Temperature with Time at Very High Flow Rate

In all the cases, the temperature of water increases from room temperature for some time till it reaches the boiling point and then the temperature remains constant. The temperature of water in the pot-4 and pot-5 is higher at any time compared to others. The boiling point of water is reached early in pot-4 and pot-5. There are three tubes in pot-4 and pot-5 whereas there is one or no tube in pot-1, 2 and 3. The heat transfer is more effective due to presence of more tubes in pot-4 and pot-5.

Effect of Fuel Flow Rate on Efficiency

It is observed from the Figure.13 that the thermal efficiency of the pots-1, 2 and 3 is more for low flow rates and it is decreased as the flow rate increases. At low flow rates, the flue gas moves slowly and most heat from the flue gas is transferred to the pots before it leaves the pots. But with increase in fuel flow rates, the flue gas moves fast and all the heat from the flue gas is not transferred to the pots and the energy lost with the escaped flue gas is more with higher flow rates. The phenomenon in pot-4 and 5 is something different from that in pots-1, 2 and 3. The number of flue tubes in pot-4 and 5 is more. The heat transfer from the flue gas in the tubes to the water inside the pots plays an important role here. The thermal efficiency of the pots-4 and 5 increases from low flow rate to medium flow rate and then decreases with increase in flow rates. At low flow rate, the convection heat transfer rate from the flue gas inside the tubes to the pot is less due to low flue gas velocity due to which the efficiency is less. But at medium flow rate, the convection heat transfer increases and the efficiency increases. As the flow rate further increases, two opposite effects come in to picture. The convection heat transfer increases whereas the heat loss through escaped flue gas also increases. At higher flow rates, the heat loss through escaped flue gas dominates the increase in convection heat transfer rate for which the efficiency decreases.

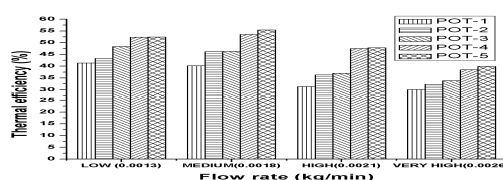


Figure 13: Efficiencies of Different Pots at Various Flow Rates

Effect of Number of Flue Tubes on Efficiency

At any fuel flow rate, the efficiency is more for pots-4 and 5 compared to pots-1, 2 and 3. This is because of more flue tubes present in the pots-4 and 5. Also, for all flow rates the efficiency of pot-3 is more compared to that of pot-1 and 2. The pot-3 is having one flue tube whereas no flue tube is present in pot-1 and 2. More heat of the flue gas is transferred to the pot for which the efficiency increases.

Effect of Shape of Bottom Surface on Efficiency

The efficiency of pot-2 is more than that of pot-1 at all flow rates. Both the pots have no flue tube, but the bottom surface of pot-2 is of concave and that of pot-1 is flat. The heat transfer in pot-2 is higher as its bottom surface area is more and the efficiency of pot-5 is more than that of pot-4. It is due to the bottom surface area of pot-5 more than that of pot-4.

CONCLUSIONS

The heat transfer in different modified pots has been investigated at different fuel flow rates. The conclusions may be made as follows:

- The boiling temperature of water reached early in pots having more number of flue tubes (pots-4 and 5) compared to pots having no or less number of flue tubes (pots-1, 2 and 3).
- The efficiency of pots having no or less number of flue tubes is more at low flow rates.
- The efficiency of pot having more number of flue tube is maximum at medium fuel flow rate.

- At any fuel flow rate, the efficiency of pots having more number of flue tubes is more compared to pots having no or less number of flue tubes.
- The efficiency of pots is more with modified bottom surface compared to flat bottom surface. The efficiency is more for pots of modified bottom surface having more surface area.

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